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Higgs-mediated Slepton Pair-production at the Large Hadron Collider.

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Abstract

At the LHC, directly pair-produced sleptons may be easier to identify than those arising in cascade decays of squarks or gluinos. Higgs exchange processes leading to such slepton pair-production are calculated to one-loop in the MSSM. It turns out, surprisingly, that their total contribution can dominate the usual Drell-Yan production in certain regions of the parameter space. In particular, an interesting region with low $\tan\beta$ is covered by the dominant exchange of the heavier neutral scalar H^0.

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The Minimal Supersymmetric Standard Model (MSSM) [1] is a promising candidate for physics beyond the Standard Model. If supersymmetry is to stabilize the electroweak scale and the masses of fundamental scalar fields, then the sparticles should have masses below a few TeV [2]. This is also the mass window in which the Higgs bosons of the MSSM are expected to lie. It is expected, therefore, that supersymmetry could be discovered at the Large Hadron Collider (LHC). The lightest sparticle (LSP), presumed to be the lowest mass neutralino and stable on account of R-parity conservation, would escape detection leading to distinctive missing transverse energy ($\not\!\!E_T$) signals. The absence of such signatures has already enabled the lower energy LEP-1, LEP-1.5 and Tevatron colliders to generate constraints on sparticle masses and couplings. In this letter one clear signal for supersymmetry is discussed, namely, direct electroweak hadroproduction of a pair of charged or neutral sleptons which subsequently decay to acollinear unlike-sign but like-flavor dileptons with $\not\!\!E_T$. Earlier studies with respect to the Tevatron [4] have shown a large Standard Model background from W^+W^- production swamping this signal. At the LHC, however, the event rate is expected to be larger (because of the higher energy and gluon luminosities) so that more stringent kinematic cuts can be applied to eliminate backgrounds leaving [4] a visible and tractable signal.

Sleptons might also appear in cascade decays of squarks and gluinos. However, if the latter are close to 1 TeV in mass, they would be beyond the reach of the Tevatron — even after a luminosity upgrade — and would be produced in small numbers in the initial runs of the LHC due to phase-space limitations. On the other hand, sleptons can be as light as a hundred GeV or so. (In supergravity-constrained models, for example, light slepton masses are expected if the squark and gluino masses are roughly equal.) Searching for directly produced low-mass slepton pairs may, then, be more fruitful than waiting for enough squark and gluino events to build up for cascade decay signals to be viable. Alternatively, squarks and gluinos could be of lower mass and hence be produced bountifully in hadron colliders.

For instance, with masses $\sim 200\,\mathrm{GeV}$, they could be seen at the upgraded Tevatron. Even heavier ($\sim 500\,\mathrm{GeV}$) ones could be produced copiously at the LHC. Sleptons could then occur in cascades, but would not be easily distinguishable [4] from cascade-produced charginos or neutralinos. In contrast, such a distinction seems to be achievable [4] in the case of direct electroweak production of slepton pairs. Moreover squarks and gluinos may also decay directly into LSP's with very small branching fractions for sleptonic modes. There are two additional advantages for directly produced slepton pairs: (i) with only hard multileptons detected, the events would be hadronically quiet, so that cuts on hadronic activity could suppress backgrounds such as $t\bar{t}$, provided there is an efficient veto on soft jets; (ii) leptons arising from directly pair-produced sleptons must be of the same flavor unlike those coming from W^+W^-. Considering all these aspects, it is clearly worthwhile to look at direct electroweak pair-production of sleptons at hadron colliders. A complete and reliable calculation of the total electroweak production rate is first required before the signals for sleptons can be analyzed.

Any of the following four mechanisms can lead to significant slepton pair-production: (i) gluon fusion through a top or stop loop to produce a s-channel neutral Higgs boson intermediary, h^0, H^0, or A^0, which goes into a slepton pair[1]; (ii) Drell-Yan production in which a $q\bar{q}$ pair goes into a slepton pair through s-channel γ and/or Z^0 exchange or a pair of dissimilar quarks $q\bar{q}'$ form a charged-neutral slepton pair ($\widetilde{\ell}^-\widetilde{\nu}_\ell^*$, $\widetilde{\ell}^+\widetilde{\nu}_\ell$) through $W^\pm$-exchange; (iii) W^+W^- fusion; (iv) $b\bar{b}$ (or $c\bar{c}$) sea-quark annihilation to slepton pairs through s-channel exchange of neutral scalars h^0, H^0, A^0. Though (iv) has not been discussed in the literature, (i), (ii), (iii) have been [3, 4, 5]. In particular, del Aguila and Amettler [5] found the Drell-Yan mode to be dominant, W^+W^- fusion to be an order of magnitude smaller (in general)

[1]The amplitude for Z^0-mediated gluon fusion into a slepton pair vanishes [5]. Also, A^0-exchange contributes only to the $\widetilde{\ell}_L^\pm\widetilde{\ell}_R^\mp$, amplitudes which are suppressed by m_ℓ/M_W in the coupling.

and gluon fusion to be smaller still. In their analysis, only the exchange of the lightest neutral Higgs, h^0, was considered in gluon fusion; the two other neutral Higgs bosons H^0, A^0 were assumed to be very heavy ($\sim 1\,\mathrm{TeV}$) and neglected. However, large regions of the MSSM parameter space exist where H^0 is much lighter and can make a substantial contribution to the gluon fusion mode of production for sleptons. The analysis by the authors of Ref. [5] was, therefore, incomplete. Moreover, they did not consider 1-loop radiative corrections to Higgs masses which are now known to push the upper bound on m_h to about $130\,\mathrm{GeV}$ [6]; this, in fact, increases the h^0-contribution to the process. Subsequently Ref. [4] concentrated on Drell-Yan production only, taking the conclusions of Ref. [5] to justify their neglect of gluon fusion.

The results of a more complete analysis of slepton pair-production are presented here. The h^0-contribution — even after 1-loop corrections, remains small, exceeding the Drell-Yan part only for slepton masses between roughly 50 and $60\,\mathrm{GeV}$. This can be seen in the high $\tan\beta$ curves in Fig. $1(a)$. In contrast, H^0-exchange which covers an interesting part of the parameter space with low $\tan\beta$ and m_A (consistent with supergravity constraints [7]) turns out to be dominant and yields a cross-section which is significantly larger than that from all other mechanisms including the Drell-Yan one. Thus slepton pairs can be produced more copiously than was thought previously; moreover, the kinematic distribution of the produced sleptons may differ from the Drell-Yan case which might prove an aid to detection.

Gluon fusion to Higgs bosons takes place through quark (q) and squark ($\widetilde{q}$) mediated one-loop diagrams [8]. Since the Yukawa couplings of the Higgs bosons to $q(\widetilde{q})$ pairs are proportional to m_q/M_W, the $t(\widetilde{t}_L, \widetilde{t}_R)$ loops dominate though all $q(\widetilde{q})$ loops have been included in the numerical calculation. Off-shell effects from the exchanged Higgs bosons have been included; however, the dominant contributions come when the Higgs bosons are on-shell, since the resonances are rather narrow. Interference terms involving different scalars in the

propagator are, therefore, small and have not been presented in the formulae below.

The Higgs interactions relevant here are

$$\mathcal{L}_I^{Higgs} = \sum_{S=h,H} e\Big[\mathcal{A}_{S\widetilde{\ell}\widetilde{\ell}^*} S\widetilde{\ell}\widetilde{\ell}^* + \mathcal{A}_{S\widetilde{q}\widetilde{q}^*} S\widetilde{q}\widetilde{q}^* + S\bar{q}(\mathcal{A}_{Sq\bar{q}} + \mathcal{A}'_{Sq\bar{q}}\gamma_5)q\Big] + \text{h.c.}\,, \tag{1}$$

where the couplings $\mathcal{A}_{S\widetilde{\ell}\widetilde{\ell}^*}, \mathcal{A}_{S\widetilde{q}\widetilde{q}^*}, \mathcal{A}_{Sq\bar{q}}, \mathcal{A}'_{Sq\bar{q}}$ can be easily read off from Ref. [9]. We use the symbol $\widetilde{\ell}$ generically for both sneutrinos $\widetilde{\nu}$ and charged sleptons $\widetilde{\ell}^{\pm}_L, \widetilde{\ell}^{\pm}_R$. The slepton pair-production cross-section through gluon fusion is

$$\sigma_{gluon}(pp \to \widetilde{\ell}\widetilde{\ell}^* + X) = \frac{1}{16\pi s^2} \sum_{S=h,H} \int \frac{dx_1}{x_1^2}\frac{dx_2}{x_2^2}\; f_{p/g}(x_1)\; f_{p/g}(x_2) \int d\hat{t}\;\; \mid \overline{\mathcal{M}} \mid^2_{gluon}, \tag{2}$$

$$\mid \overline{\mathcal{M}} \mid^2_{gluon} = \frac{1}{4}\frac{\alpha\alpha_s^2 \mid \mathcal{A}_{S\widetilde{\ell}\widetilde{\ell}^*} \mid^2}{(\hat{s} - m_S^2)^2 + (m_S\Gamma_S)^2}$$
$$\times \Big[\mid \tau_q^{-1}\mathcal{A}_{Sq\bar{q}} F_{1/2}(\tau_q) + (2\tau_q)^{-1}\mathcal{A}_{S\widetilde{q}\widetilde{q}^*} F_0(\tau_{\widetilde{q}}) \mid^2 + m_S^2\tau_q \mid \mathcal{A}'_{Sq\bar{q}} f(\tau_q) \mid^2 \Big],$$

where $\tau_q = 4m_q^2/\hat{s}$, $\tau_{\widetilde{q}} = 4m_{\widetilde{q}}^2/\hat{s}$ and the functions $F_{1/2}, F_0, f$ are given in Appendix C of Ref. [8]. In the above, s is the square of the pp center-of-mass energy and $\hat{s}, \hat{t}$ are the Mandelstam variables for the subprocess in the parton center-of-mass frame. Notations for the mass parameters are self-explanatory.

While calculating the widths [10] of the scalars $S = h^0, H^0$ in the Breit-Wigner form of the propagator, all possible decay channels allowed by the respective masses for the Higgs bosons are included. The masses are calculated in terms of the MSSM parameters including radiative corrections to the self-energies from t $(\widetilde{t}_L, \widetilde{t}_R), b$ $(\widetilde{b}_L, \widetilde{b}_R)$ loops[2]. Parton distributions are taken from the recent MRS(A′) parametrization of Martin, Roberts and Stirling [11], though their numerical values do not differ significantly from earlier parametrisations (*e.g.* those used in Ref. [5]) at the scale $Q^2 \sim 10^4\,\text{GeV}^2$. Both left and right charged sleptons are considered. Formulae similar to (2) hold for the cases of Drell-Yan production and $b\bar{b}$

[2]These corrections are relatively small for the H^0 which makes the largest contribution to gluon fusion in the interesting region of parameter space.

annihilation; these will be presented elsewhere. Finally, W^+W^- fusion terms, calculated using the effective-W approximation in the limit of high energies [12], are at least an order of magnitude smaller than Drell-Yan production and can be safely ignored.

QCD corrections to the gluon fusion amplitude have not been included. This makes our estimates of Higgs exchange rates somewhat conservative since these corrections are known to *increase* gluon fusion rates by a factor as large as 1.5 [13]. QCD corrections to Drell-Yan production of slepton pairs, which result mainly from the annihilation of light quarks, have been neglected; those to lepton pair-production at these energies are known [14] to be small and these are expected to be reduced further for heavier mass sleptons. However, for $b\bar{b}$ annihilation, radiative corrections [15] drive the cross-section *down* to about a quarter of the tree-level result; these corrections have, therefore, been incorporated in our calculation.

The dominance of Higgs exchange over the Drell-Yan process as a production mode in a region of the allowed parameter space is illustrated in Figs. 1 (*a*-*c*). In Fig. 1(*a*) cross-sections for the production of *one* species of sneutrino are plotted against its mass $m_{\tilde{\nu}}$. The mass m_A of the pseudoscalar Higgs has been fixed at 225 GeV for definiteness; other input parameters are listed in the next paragraph. Solid lines correspond to the total Higgs-mediated cross-sections (gluon fusion plus $b\bar{b}$ annihilation) for the marked values of $\tan\beta$. The values 1 and 1.5 of $\tan\beta$ may not be completely consistent with the full supergravity constraints at the grand unification scale and radiative electroweak symmetry-breaking, but are allowed if the universal scalar mass assumption is partially relaxed. Though gluon fusion with H^0 exchange is the dominant mechanism, the $b\bar{b}$ annihilation process gives about a third as much for $\tan\beta \simeq 3-5$. The dashed line shows the Drell-Yan cross-section with γ and Z^0 exchanges, which is independent[3] of $\tan\beta$. Evidently, given a low $\tan\beta$, Higgs exchange

[3]This is strictly true for sneutrinos where there is no left-right mixing. For charged selectrons there is a dependence on $\tan\beta$ which appears in the mixing matrix, but this is very weak since the relevant term is

is dominant for $m_{\widetilde{\nu}}$ from $60 - 70\,\mathrm{GeV}$ to around $120\,\mathrm{GeV}$ at which point the exchanged H^0 goes off-shell. With increasing $\tan\beta$, this cross-section falls quite dramatically — to a negligible level for $\tan\beta > 3$. Thus $b\bar{b}$ annihilation, which is significant only in this region, *is always a small part of* the net cross-section (see Table 1). In Fig. 1(b) a similar plot for the pair-production of right selectrons has been shown using the same conventions. Gluon fusion dominates the Drell-Yan mode for $m_{\widetilde{e}_R} > 80\,\mathrm{GeV}$ and $\tan\beta \simeq 1$ and remains comparable upto $\tan\beta = 2$. Fig. 1(c) illustrates the situation for left selectron pairs, where the two modes are comparable at best and Drell-Yan production becomes dominant for $\tan\beta > 1$.

We now comment on the choice of parameters. Heavy quark masses are taken to be $m_t(m_b) = 175(5)\,\mathrm{GeV}$; all squark masses are set to $1\,\mathrm{TeV}$ and the gluino mass is $900\,\mathrm{GeV}$, while $\mu = -250$ GeV and $A_t = A_b = -500\,\mathrm{GeV}$. This constitutes a reasonable choice of parameters in the MSSM, but is not the optimal one for slepton pair-production. $SU(2)_L$-invariance predicts the equality of the soft supersymmetry-breaking masses of $\widetilde{\ell}_L$ and $\widetilde{\nu}_\ell$ for each generation, leaving six free input parameters in the slepton mass sector[4]. For simplicity, the soft SUSY-breaking slepton masses are chosen to be flavor-degenerate in the left and right sectors separately, the latter being slightly greater than the former. A typical (not necessarily optimal) soft mass-squared difference of $20\,\mathrm{GeV}^2$ between left and right sleptons is taken, corresponding to a mass difference of about $0.1\,\mathrm{GeV}$ for soft masses of $\sim 100\,\mathrm{GeV}$.

Since soft-supersymmetry breaking stau masses have been taken to be degenerate with selectron and smuon soft masses, intra-flavor left-right mixing drives the lighter physical stau mass below the other charged slepton masses. This increases the total Higgs width in the Breit-Wigner denominator, decreasing the selectron pair-production rates. If, on the

suppressed by m_ℓ/M_W.

[4]The physical masses, always denoted by $m_{\widetilde{\ell}}$ in this letter, become different because of electroweak symmetry-breaking and mixing, the latter being significant only for staus. Inputs such as $\tan\beta$ and μ entering via these effects are not counted among the six parameters; further, A_ℓ-terms are neglected.

other hand, staus and/or smuons are much heavier than the selectrons, then selectron pair-production rates are increased. Of course, *overall* slepton production rates go up as more slepton species are made light. Supergravity models predict $m_{\widetilde{\ell}_L} > m_{\widetilde{\ell}_R}$; in these scenarios the $\widetilde{\ell}_R^{\pm}$ pair-production rate for a given $m_{\widetilde{\ell}_R}$ will be somewhat larger than what is shown in our figures while that for $\widetilde{\ell}_L^{\pm}$ pair-production will be smaller by reasoning analogous to that for the stau effect described above. Lowering the gluino mass, which would result in lower chargino and neutralino masses and potentially open some more decay channels for the Higgs bosons, can also reduce slepton pair production rates. However, the effect of halving the gluino mass from its given value was found to be quite small, mainly due to the relative insensitivity of the LSP mass to the gluino mass. Lowering stop masses to $\sim \mathcal{O}(500\,\mathrm{GeV})$, on the other hand, increases (mainly due to the a decrease in the $H^0 \to h^0 h^0$ partial decay width) cross sections for $\tan\beta < 3$ by about 5 - 25 %; however, the LEP-1 bound on m_A also increases, especially for $\tan\beta$ less than 2, and rules out some of this parameter space region. Our choice of stau masses also affects the region excluded by LEP-1 since $m_{\widetilde{\tau}_1} < 45\,\mathrm{GeV}$ and all other slepton masses $> \frac{1}{2}M_Z$ are possible for high $\tan\beta$. (The LEP-1 excluded region is taken as $m_{\widetilde{\nu}} < 43\,\mathrm{GeV}$ and $m_{\widetilde{\ell}}^{\pm} < 45\,\mathrm{GeV}$ [16] and depicted in Fig. 1 as dotted segments which terminate where slepton masses become unphysical.)

For $m_{\widetilde{\nu}} = 90\,\mathrm{GeV}$, Fig. 2($a$) illustrates the region in the (m_A – $\tan\beta$) plane for which the contribution from Higgs exchange to sneutrino pair-production is comparable to Drell-Yan production. The solid lines show contours of the ratio $R \equiv \sigma_{Higgs}/\sigma_{Drell-Yan}$ when $R \geq 1$, while dashed lines show $R < 1$. The region with relatively low values of both m_A and $\tan\beta$ favors gluon fusion via Higgs exchange (and also corresponds to subdominant $b\bar{b}$ annihilation). This is because the factor $\cos(\beta+\alpha)$ which appears in the coupling of the heavier scalar H^0 to sleptons is large. The correspondingly small value of $\sin(\beta+\alpha)$

suppresses the coupling of the light h^0 to sleptons[5]. In contrast, higher values of $m_A, \tan\beta$ suppress the couplings of the H^0 and increase those of the h^0. The latter, however, mediates contributions which are always smaller than the Drell-Yan term, essentially because the upper bound of about 130 GeV [6] on the mass m_h drives the exchanged h^0 off-shell for all but the lightest slepton masses. As a result, gluon fusion becomes subdominant for large $\tan\beta$. As expected, the importance of the essentially on-shell H^0-exchange declines sharply when the $H^0 \to t\bar{t}$ channel opens up. Fig. 2(b) shows similar contours for the pair-production of $\widetilde{e}_R$. The cross-section with Higgs exchanges is no longer so strongly dominant over Drell-Yan production as in the case for sneutrinos (see Fig. 1(b)) and this shows up in the smaller region in parameter space where the former is significant. The situation is somewhat worse for $\widetilde{e}_L$, as shown in Fig. 2(c). No LEP-1 excluded region is present in Fig. 2 with our choice of stop masses $\simeq 1$ TeV, though a large part of the region below $\tan\beta \sim 2$ becomes excluded if stop masses are lowered to 300-500 GeV as discussed in the preceeding paragraph.

Figs. 3 (a-c) show contours of the Higgs-mediated cross-section in the $(m_A, m_{\widetilde{\ell}})$ plane for the pair production of sneutrinos, right selectrons and left selectrons, respectively, for a fixed $\tan\beta$. The region to the left of (below) the vertical (horizontal) dash-dot line is excluded by LEP-1 limits on h^0 (sleptons) [16]. The thick line on each plot corresponds to $m_H = 2m_{\widetilde{\nu}}$ and delineates the region of off-shell H^0-exchange where the cross-sections are seen to be quite small. The contours are rather similar in each case, as might be expected, though sneutrino pair-production has the largest cross-sections. Assuming (conservatively) an integrated luminosity of $10\,\text{fb}^{-1}$ at the LHC, Fig. 3(a) shows that if $m_A \sim 500$ GeV, one can probe sneutrino masses as high as 150 GeV with some 50 odd sneutrino pairs produced though kinematic cuts would reduce the cross-section somewhat. For a lighter $m_A \simeq 300$ GeV thousands of events can be expected.

[5]The F-term contributions to the couplings which do not contain these factors are suppressed by m_ℓ/M_Z.

Thus, for sneutrino masses in the range $45 - 140\,\mathrm{GeV}$ and charged slepton masses in the range $80 - 140\,\mathrm{GeV}$, *the H^0-mediated gluon-fusion amplitude will be the dominant contribution* at the LHC for low values of $\tan\beta$ in the range $1 - 3$. The Higgs-mediated cross-section for slepton masses in the ballpark of 100 GeV can be as high as 1.5 pb, which is several orders of magnitude larger than values quoted earlier [4, 5]. Detection would best be through a final state lepton pair (of the same flavor) and hard $\not{E}_T$, since each slepton will decay into a lepton and the LSP. This is especially so for the right slepton which does not have a chargino decay mode. The main backgrounds are $t\bar{t}$ production and W-boson pair-production, the former outstripping the latter at the LHC. A combined requirement of hadronically quiet events and isolated leptons with a cut of $p_{_T} > 20\,\mathrm{GeV}$ was shown in Ref. [4] to essentially eliminate the $t\bar{t}$ and W^+W^- backgrounds. The slepton masses that make our signal most favorable are also broadly the preferred masses in Ref. [4]. As our signal cross-section can be considerably larger than theirs, most of their arguments would go through. Moreover, since most of our sleptons come from nearly on-shell H^0 bosons, each of them would tend to have a harder $p_{_T}$ distribution than that predicted in Ref. [4] with a Jacobian peak. Some relic features of such $p_{_T}$ characteristics may survive in the dilepton signal, depending upon the kinematic cuts and the amount of smearing due to the Hiigs boson's momentum. Thus it might be possible to obtain a cleaner signal for slepton pair-production than has been hitherto predicted. We do not go into more details of the signal analysis since we feel that this calls for a separate investigation.

To summarize, direct electroweak pair-production of sleptons has been shown to have potential advantages over that from cascade decays of squarks and gluinos. At the LHC, Higgs-exchange terms are not always negligible as claimed in previous studies. In fact, the H^0-mediated contribution (mainly from gg fusion, with a subdominant $b\bar{b}$ annihilation component) can win over the Drell-Yan cross-section for low $\tan\beta$ and a relatively low

m_A. The bulk of the former is via a resonant on-shell H^0, off-shell effects being small. The resulting rates remain large for slepton masses beyond the potential reach of LEP-2. Previous signal analyses should not only carry through but be strengthened by the higher rates now predicted. Thus, Higgs-mediated contributions may play an important role in slepton searches at the LHC and need to be studied carefully in any analysis of such signals for supersymmetry.

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Table Caption

Table 1. Percentages of a given slepton pair produced via the various production modes. Each slepton mass is fixed at 100 GeV and $m_{_A}$ at 225 GeV. Other values are as in Fig. 1. A dash signifies a percentage of under 0.05%. W^+W^--fusion contributions, which are expected to be quite small, are not included.

Table 1

Pair	Process	$\tan\beta = 1$	1.5	1.75	2	2.5	3	5	10	15
$\tilde{\nu}\tilde{\nu}^*$	$gg \to H^0$	78.0	63.0	56.0	50.0	40.3	32.9	15.6	2.6	1.0
	$q\bar{q} \to H^0$	0.5	1.7	2.6	3.7	6.4	9.4	19.2	10.2	5.1
	$gg \to h^0$	-	-	-	-	-	0.1	0.1	0.2	0.3
	$q\bar{q} \to Z^{0*}, \gamma^*$	21.5	35.3	41.4	46.3	53.3	57.6	65.1	87.0	93.6
$\tilde{e}_R^-\tilde{e}_R^+$	$gg \to H^0$	67.1	48.1	40.6	34.7	26.3	20.8	9.8	1.6	0.6
	$q\bar{q} \to H^0$	0.5	1.3	1.9	2.5	4.1	5.9	12.0	6.1	3.0
	$gg \to h^0$	-	-	-	-	-	0.1	0.1	0.1	0.1
	$q\bar{q} \to Z^{0*}, \gamma^*$	34.2	50.6	57.5	62.8	69.6	73.2	78.1	92.2	96.3
$\tilde{e}_L^-\tilde{e}_L^+$	$gg \to H^0$	52.7	32.7	26.2	21.5	15.6	12.1	5.5	0.9	$0.3^\dagger$
	$q\bar{q} \to H^0$	0.4	0.9	1.2	1.6	2.4	3.4	6.8	3.4	$1.7^\dagger$
	$gg \to h^0$	-	-	-	-	-	-	0.1	0.1	$0.1^\dagger$
	$q\bar{q} \to Z^{0*}, \gamma^*$	46.9	66.4	72.6	76.9	82.0	84.5	87.6	95.6	$97.9^\dagger$

$^\dagger m_{\tilde{\tau}_1} = 41.8\,\text{GeV}$ for this case

Figure Captions

Fig. 1. Production cross-sections for (a) sneutrino pairs ($\widetilde{\nu}_e\widetilde{\nu}_e^*$), ($b$) right selectron pairs ($\widetilde{e}_R^+\widetilde{e}_R^-$) and ($c$) left selectron pairs ($\widetilde{e}_L^+\widetilde{e}_L^-$). Solid lines show cross-sections for Higgs exchanges (including $b\bar{b}$ annihilation plus gluon fusion) for $\tan\beta = 1, 1.5, 2, 3$ respectively for a, b, c while the dashed line is the Drell-Yan contribution. m_A is fixed at 225 GeV and the values of other parameters are given in the text.

Fig. 2. Contours of the ratio of the Higgs-exchange cross-section to the Drell-Yan cross-section for (a) sneutrino pairs ($\widetilde{\nu}_e\widetilde{\nu}_e^*$), ($b$) right selectron pairs ($\widetilde{e}_R^+\widetilde{e}_R^-$) and ($c$) left selectron pairs ($\widetilde{e}_L^+\widetilde{e}_L^-$) in the ($m_A - \tan\beta$)-plane. Solid (dashed) lines show the contours of ratio 1, 2, 3 and 5 (0.5,0.1 and 0.01) respectively. Here $m_{\tilde{\ell}} = 90$ GeV in each case.

Fig. 3. Contours in the ($m_{\tilde{\ell}} - m_A$) plane (for $\tan\beta = 1.5$) of the total cross-section for (a) sneutrino pairs ($\widetilde{\nu}_e\widetilde{\nu}_e^*$), ($b$) right selectron pairs ($\widetilde{e}_R^+\widetilde{e}_R^-$) and ($c$) left selectron pairs ($\widetilde{e}_L^+\widetilde{e}_L^-$). The cross-section in fb is written next to each contour. The region to the left of (below) the vertical (horizontal) dash-dot line is excluded by LEP-1 limits on h^0 (sleptons). The thick lines correspond to $m_H = 2m_{\widetilde{\ell}}$.

Figure 1(a)

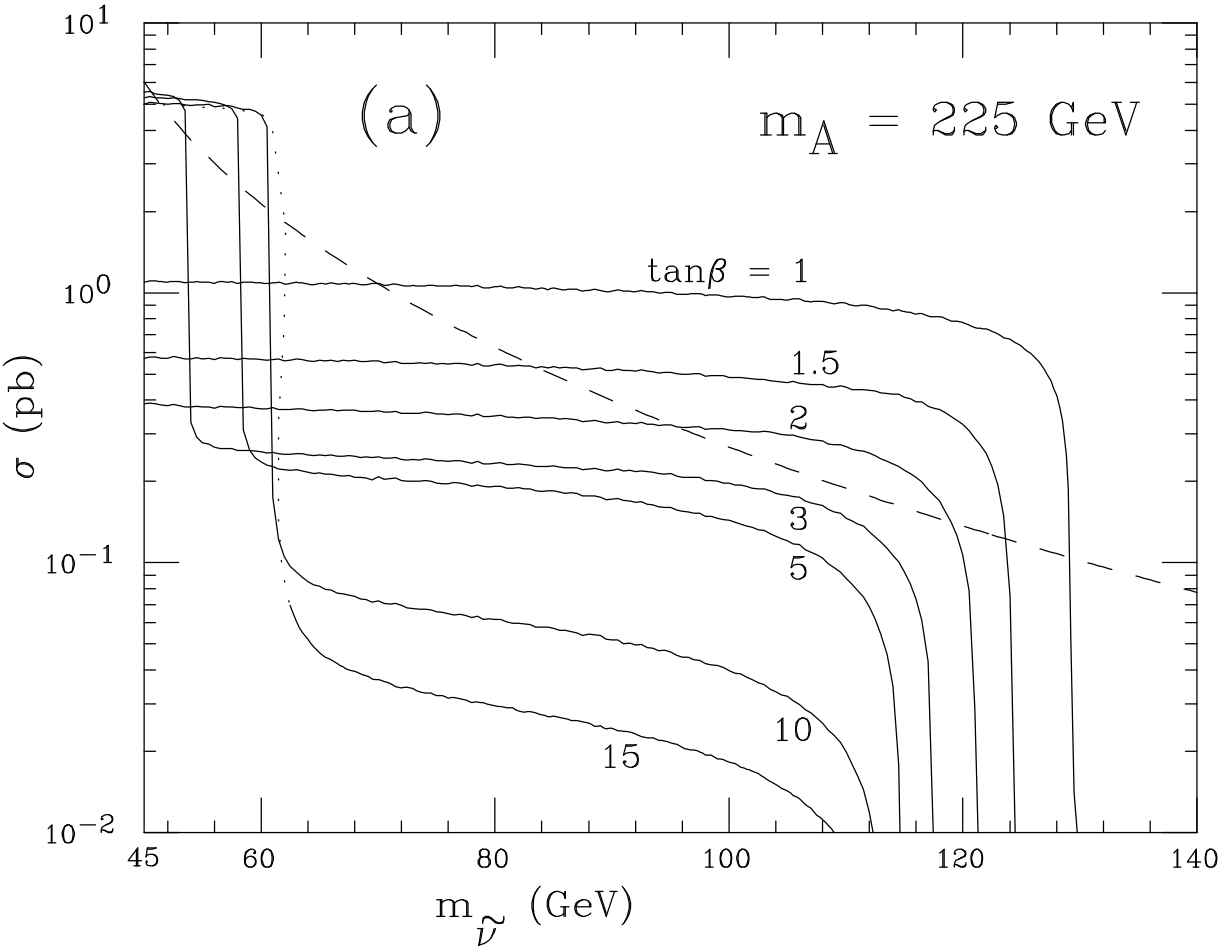

(a)
m_A = 225 GeV
tanβ = 1
1.5
2
3
5
10
15
σ (pb)
$m_{\tilde{\nu}}$ (GeV)
10^1
10^0
10^{-1}
10^{-2}
45
60
80
100
120
140

Figure 1(b)

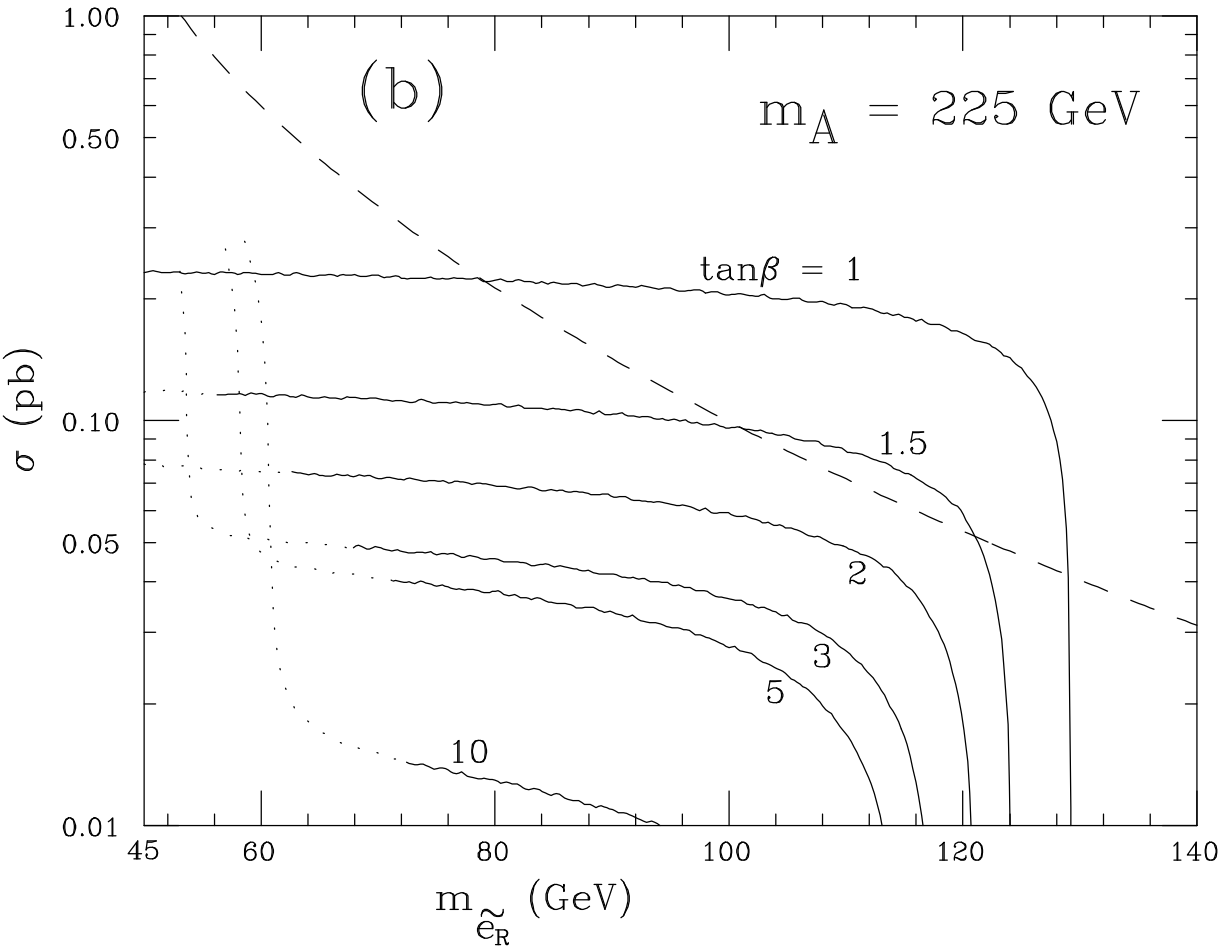

(b)
m_A = 225 GeV
tanβ = 1
1.5
2
3
5
10
σ (pb)
1.00
0.50
0.10
0.05
0.01
45
60
80
100
120
140
$m_{\tilde{e}_R}$ (GeV)

Figure 1(c)

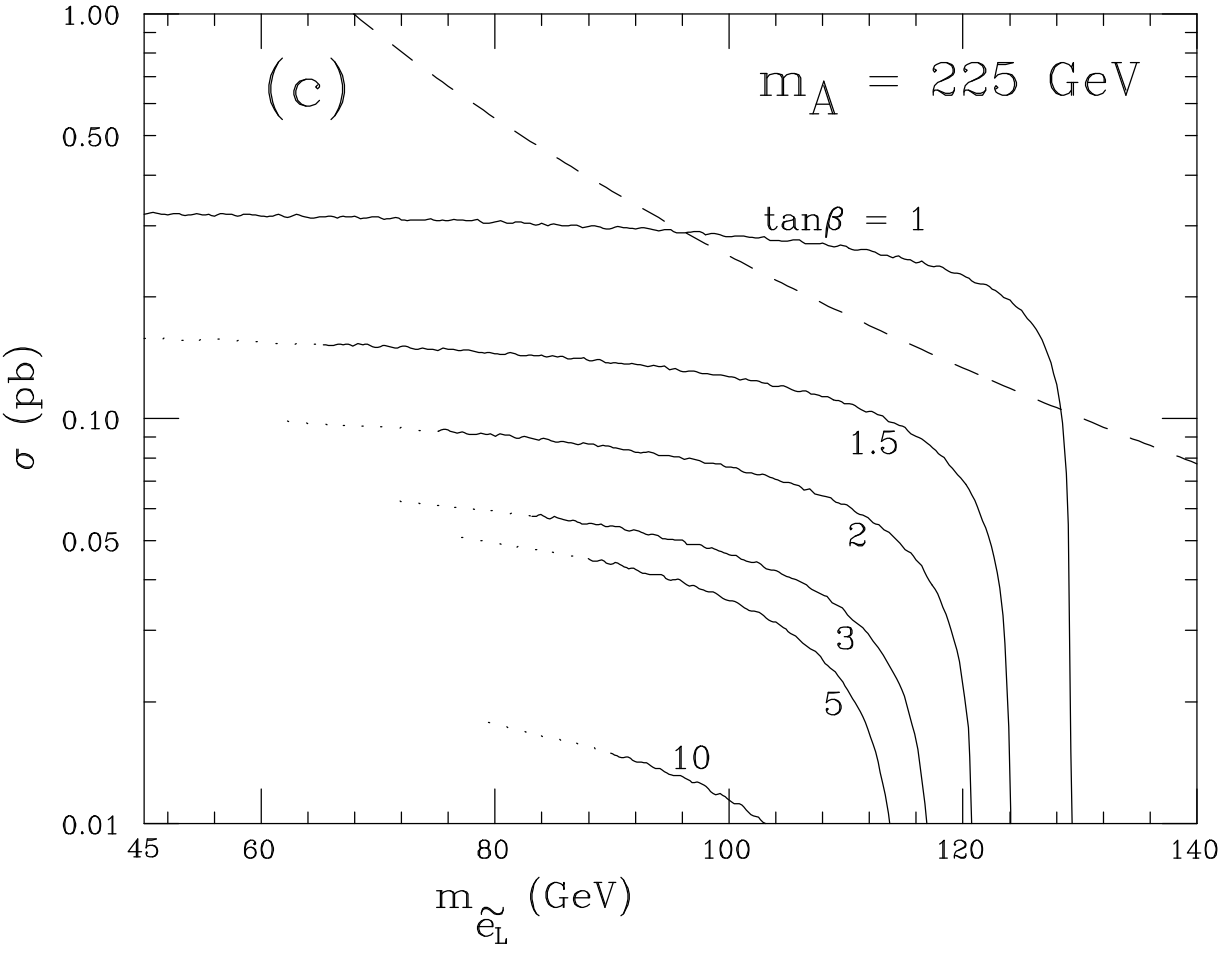

(c)
m_A = 225 GeV
tanβ = 1
1.5
2
3
5
10
σ (pb)
1.00
0.50
0.10
0.05
0.01
45
60
80
100
120
140
$m_{\tilde{e}_L}$ (GeV)

Figure 2(a)

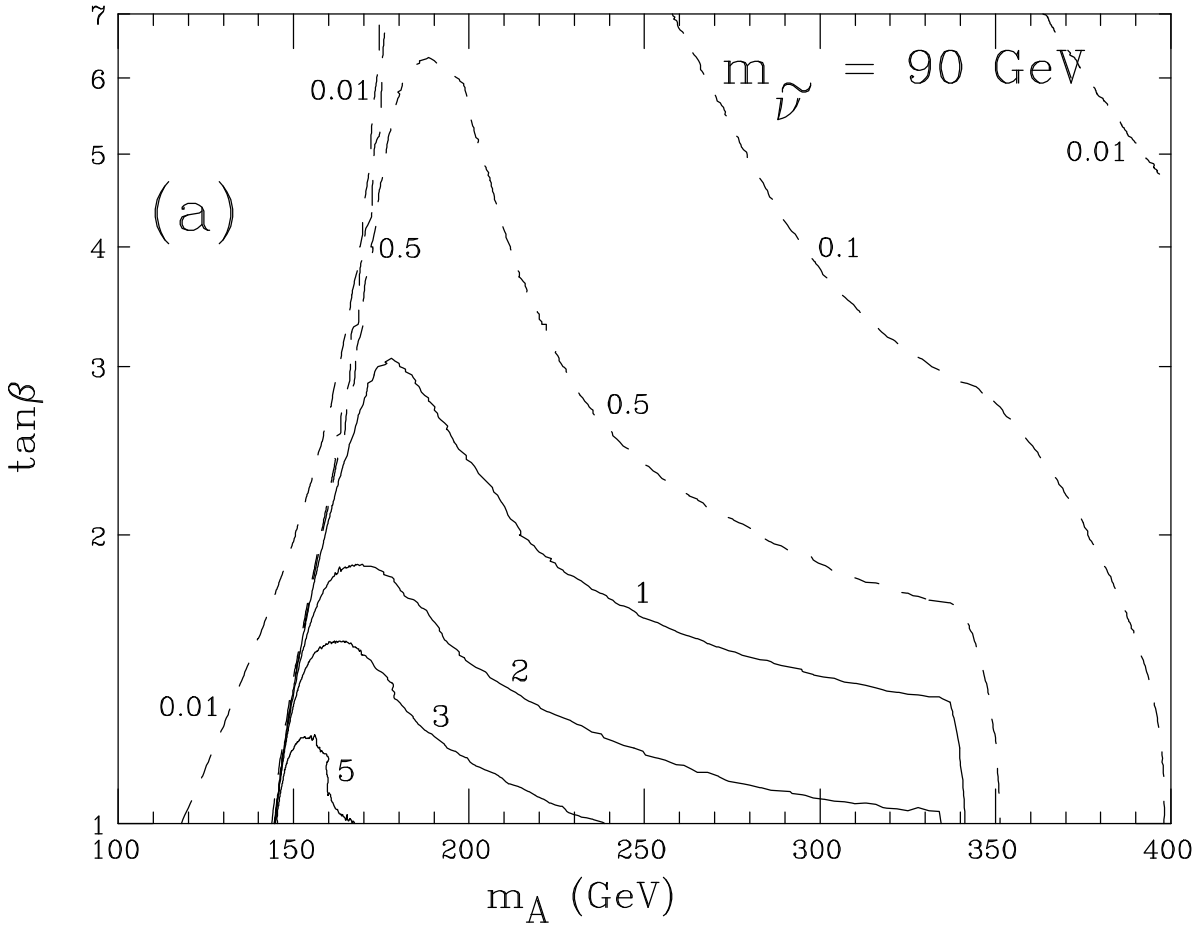

(a)
$m_{\tilde{\nu}}$ = 90 GeV
0.01
0.5
0.1
0.01
0.5
1
2
3
5
0.01
tanβ
m_A (GeV)
100
150
200
250
300
350
400
1
2
3
4
5
6
7

Figure 2(b)

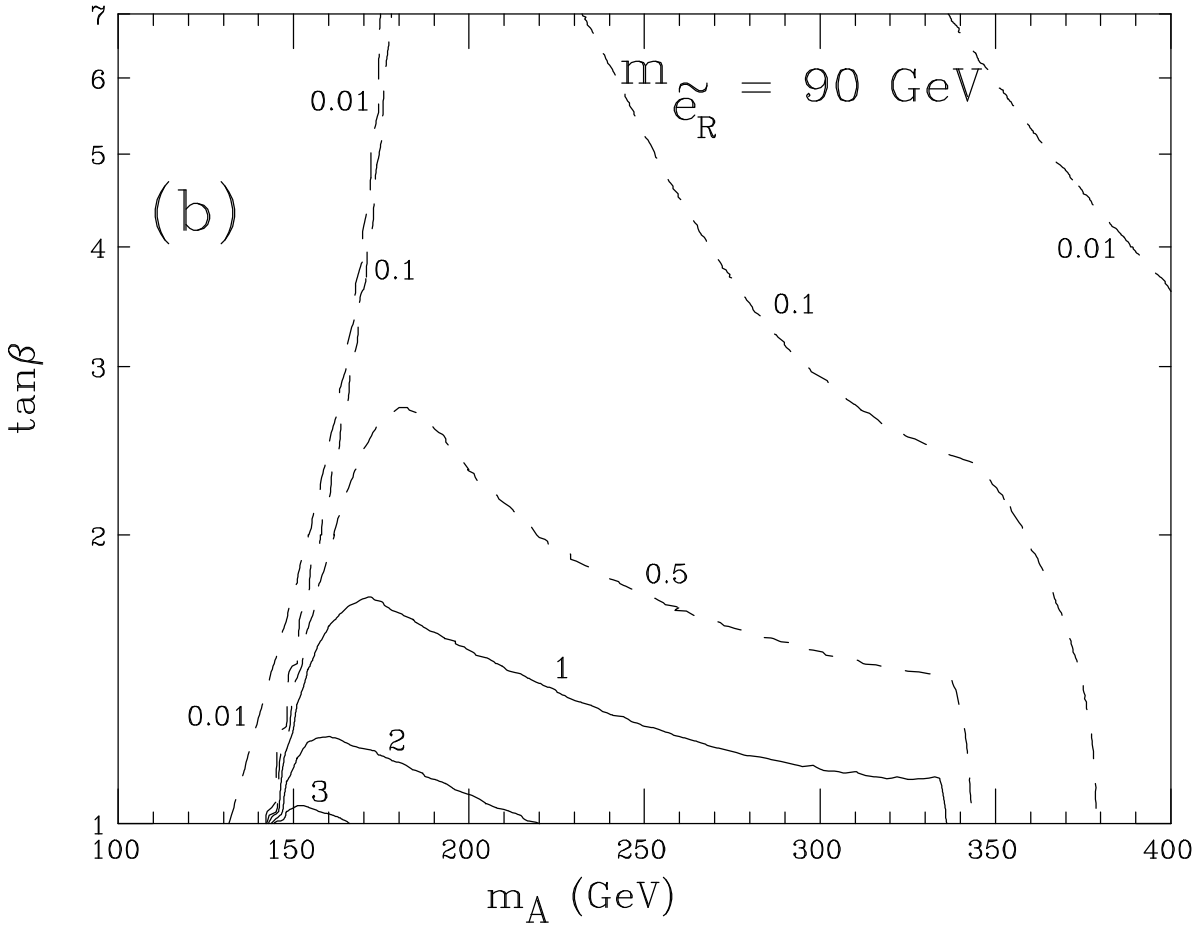

(b)
$m_{\tilde{e}_R}$ = 90 GeV
0.01
0.1
0.01
0.1
0.5
1
2
3
0.01
tanβ
m_A (GeV)
1
2
3
4
5
6
7
100
150
200
250
300
350
400

Figure 2(c)

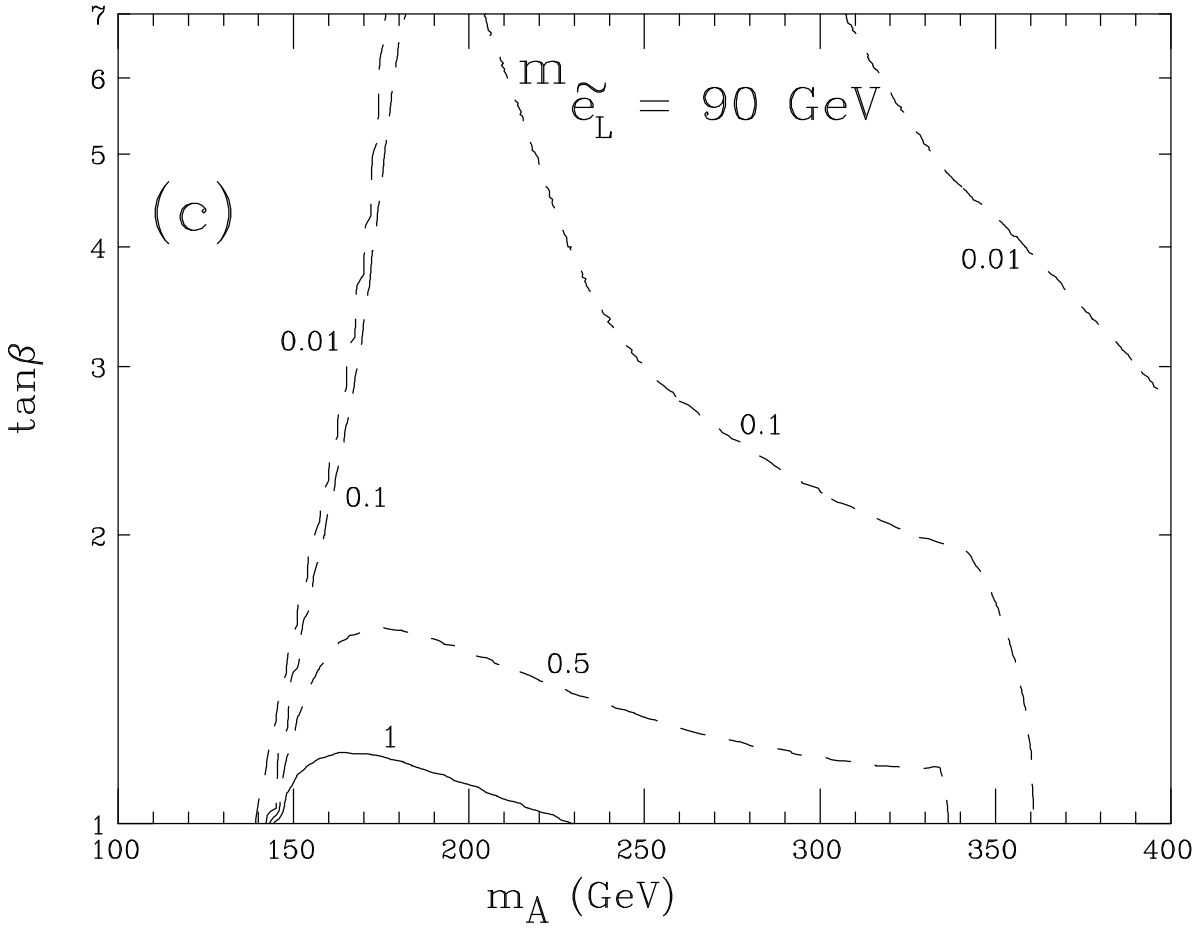

(c)
$m_{\tilde{e}_L} = 90$ GeV
0.01
0.1
0.5
1
tanβ
m_A (GeV)
1
2
3
4
5
6
7
100
150
200
250
300
350
400

Figure 3(a)

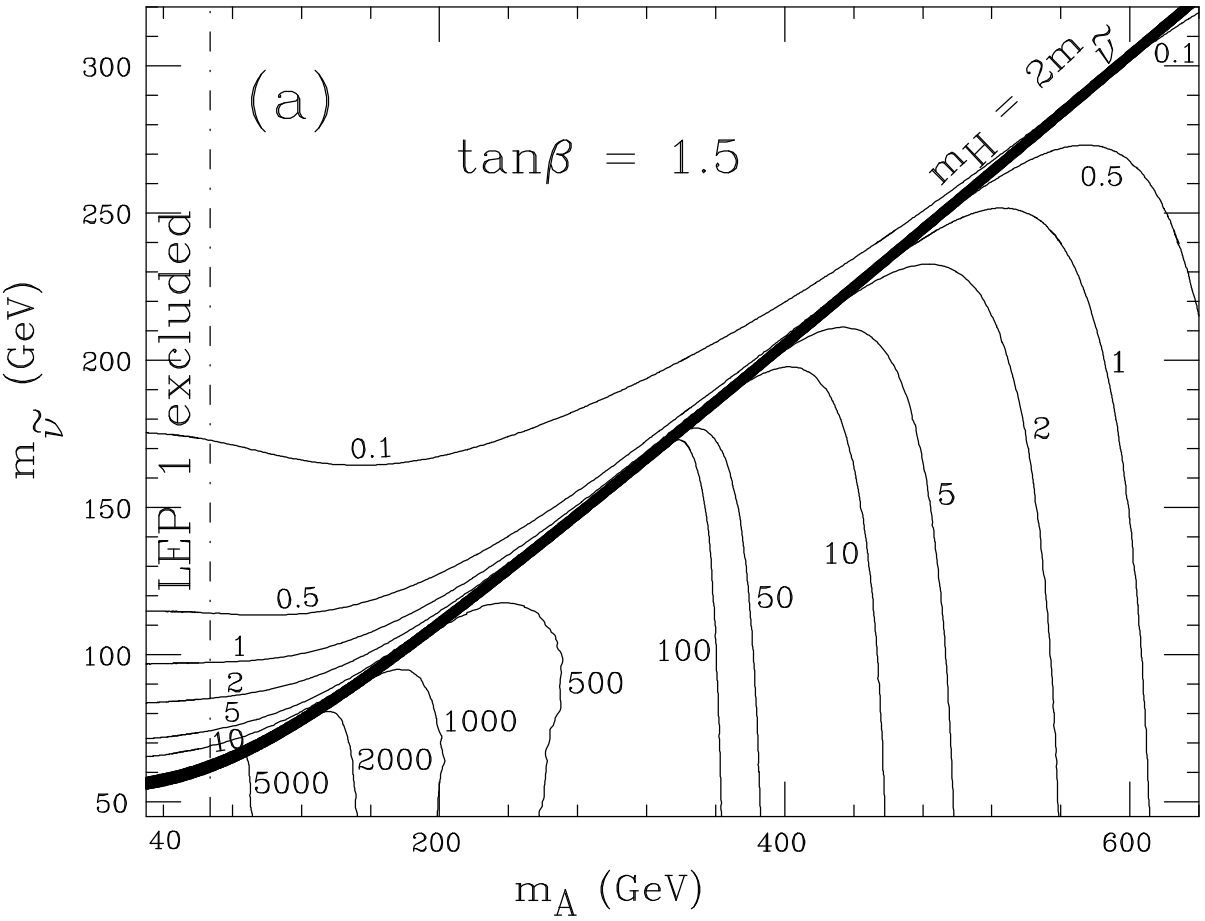

(a)
tanβ = 1.5
m_H = 2m_ν̃
LEP 1 excluded
m_ν̃ (GeV)
m_A (GeV)
0.1
0.5
1
2
5
10
50
100
500
1000
2000
5000
300
250
200
150
100
50
40
200
400
600

Figure 3(b)

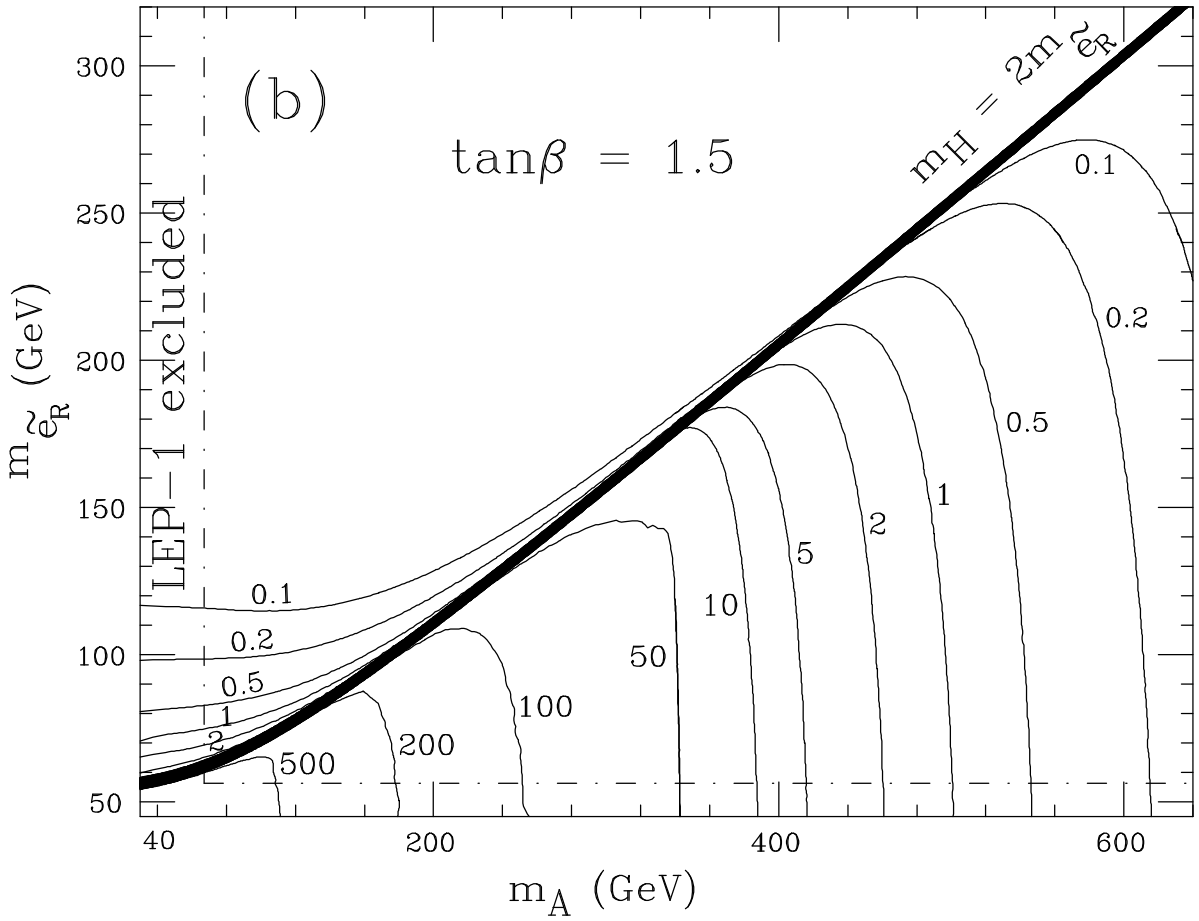
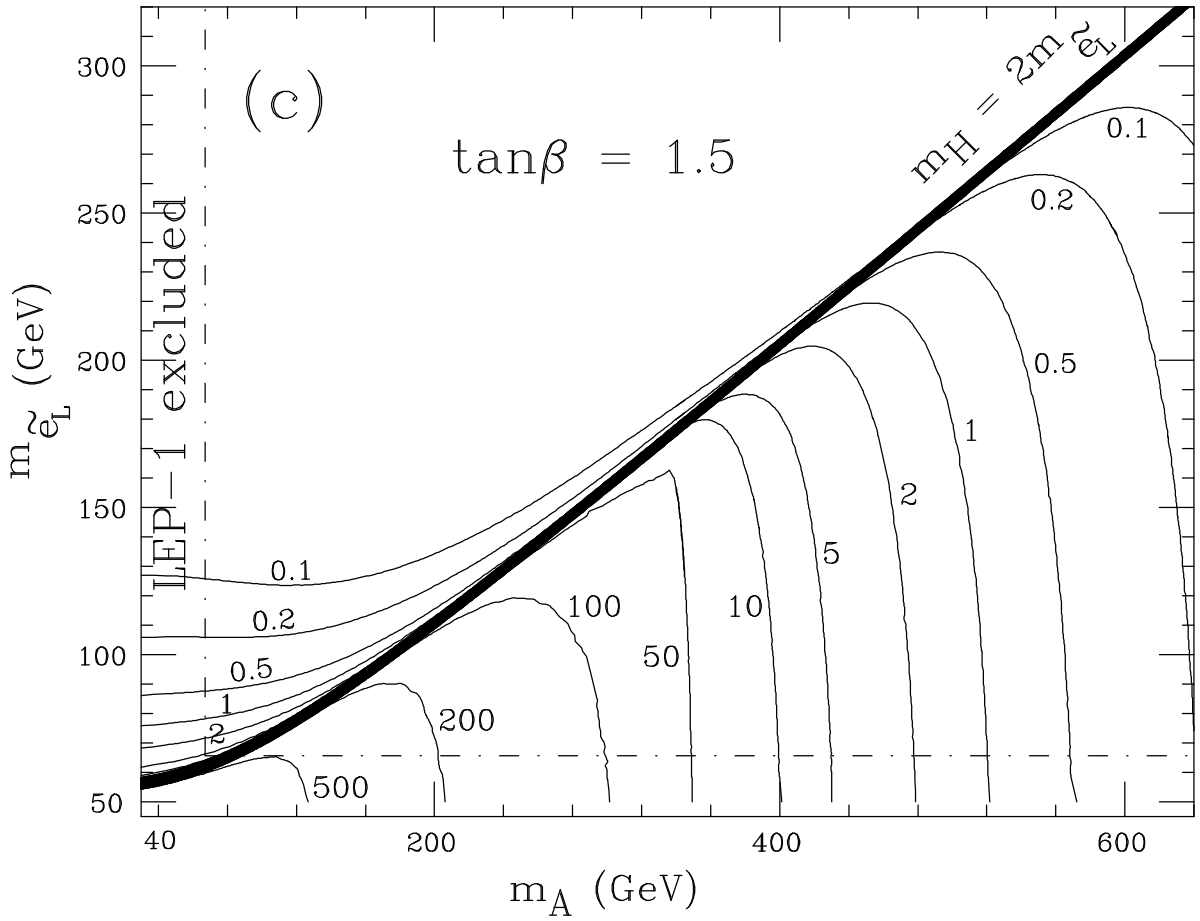

(b)
tanβ = 1.5
m_H = 2m_ẽR
LEP−1 excluded
0.1
0.2
0.5
1
2
5
10
50
100
200
500
m_ẽR (GeV)
m_A (GeV)
300
250
200
150
100
50
40
200
400
600

Figure 3(c)


(c)
tanβ = 1.5
LEP−1 excluded
m_H = 2m_ẽL
m_ẽL (GeV)
m_A (GeV)
0.1
0.2
0.5
1
2
5
10
50
100
200
500
300
250
200
150
100
50
40
200
400
600